Discussion about tT production at threshold

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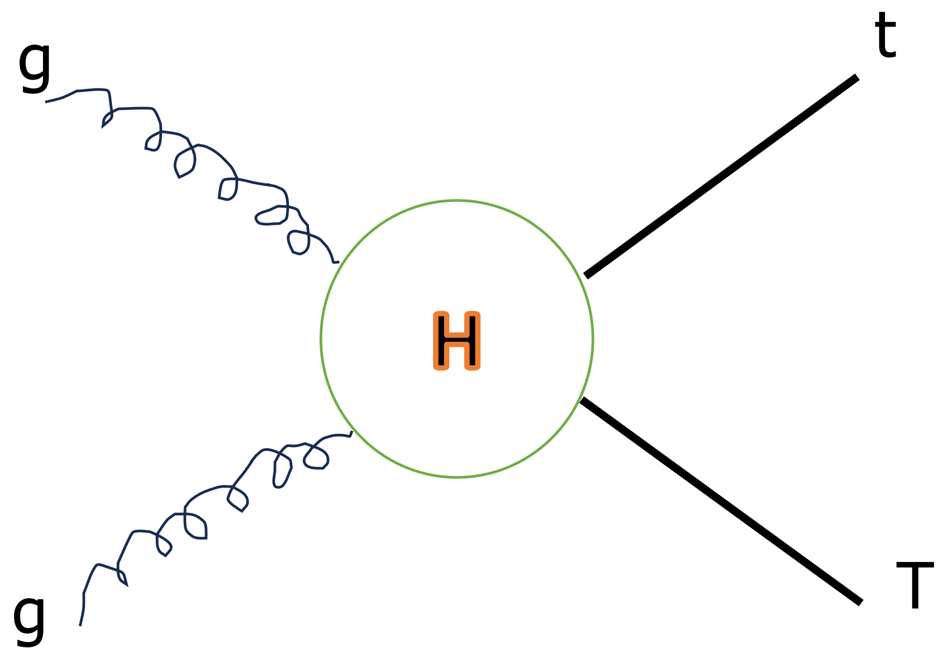
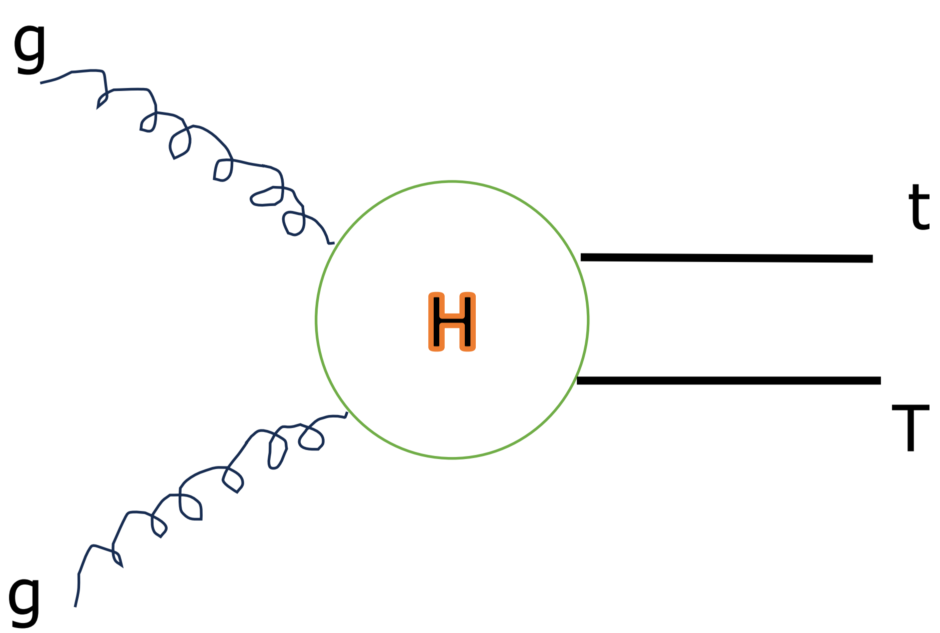
A typical representation of top pair production at the LHC

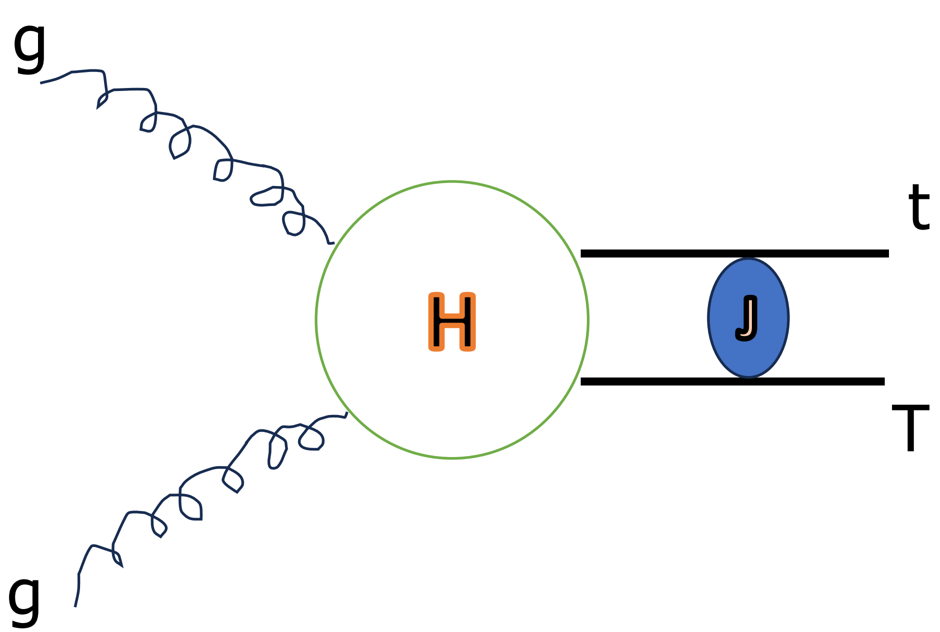


At threshold, things simplify



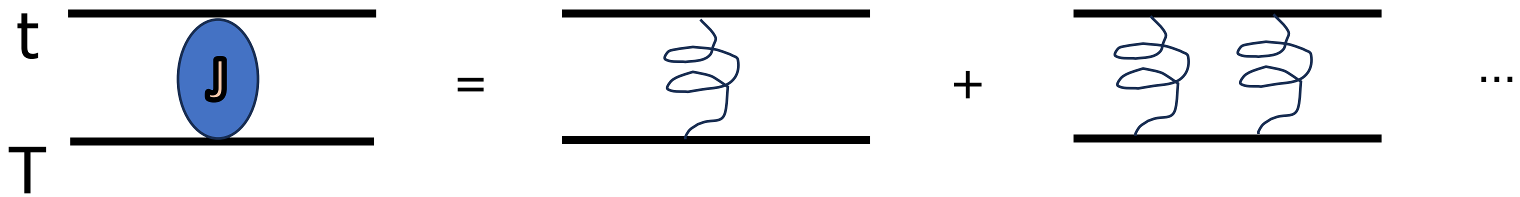
At threshold, things simplify

- ✓ But what changed?



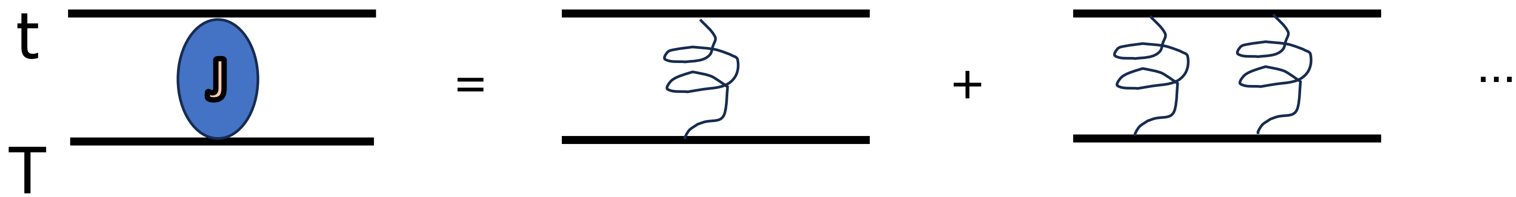
- ✓ Very close to threshold, the pair acts as a "package";
  - ✓ We have exchanges between t and T within the "package"
  - ✓ The "package" as a whole can interact with the outside world
- ✓ Physically, the t and T start forming a bound state (toponium?)

At threshold, things simplify



- ✓ Of interest are the interactions within the "package". Denoted by **J**.
  - ✓ These are Coulomb-like exchanges that make the bound-state

At threshold, things simplify

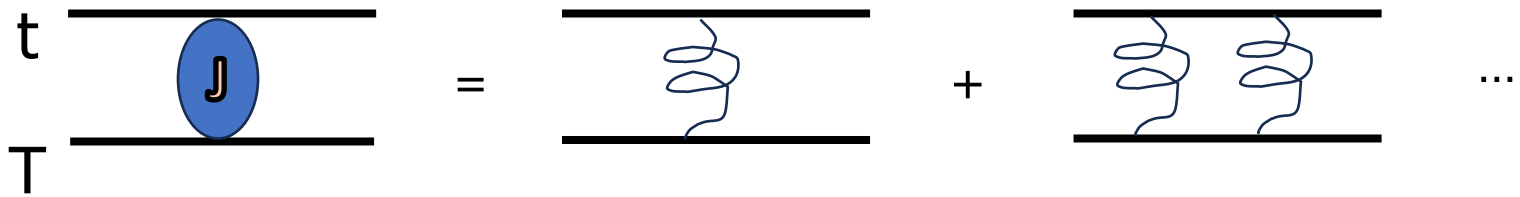


$$\sim \frac{\alpha_s}{\beta} \qquad \sim \left(\frac{\alpha_s}{\beta}\right)^2$$

where $\beta = \sqrt{1 - \frac{4m_t^2}{M_{t\bar{t}}^2}}$ Note: at threshold we have $\beta \approx 0$

The above expansion is non-convergent – all diagrams need to be summed up!

At threshold, things simplify



We can sum up:

leading power (LP) $\left(\frac{\alpha_s}{\beta}\right)^n$

next to leading power (NLP) $\alpha_s \left(\frac{\alpha_s}{\beta}\right)^n$

This results in a complicated function (Sommerfeld factor): $J \sim \frac{\alpha_s/\beta}{e^{\pi\frac{\alpha_s}{\beta}} - 1} = 1 + \frac{\alpha_s}{\beta} + \ldots$

tT at threshold: current state of the art

Tremendous amount of work in the past; first for e+e-, then for LHC.
The most recent pheno-oriented work is

Ju, Wang, Wang, Xu, Xu and Li Lin Yang arXiv:2004.0308

Relates and extends previous work:

A. Petrelli, M. Cacciari, M. Greco, F. Maltoni and M. L. Mangano, Nucl. Phys. B **514**, 245 (1998) [hep-ph/9707223].

K. Hagiwara, Y. Sumino and H. Yokoya, Phys. Lett. B **666**, 71 (2008) [arXiv:0804.1014 [hep-ph]].

Y. Kiyo, J. H. Kuhn, S. Moch, M. Steinhauser and P. Uwer, Eur. Phys. J. C **60**, 375 (2009) [arXiv:0812.0919 [hep-ph]].

M. Beneke, P. Falgari and C. Schwinn, Nucl. Phys. B **842**, 414 (2011) [arXiv:1007.5414 [hep-ph]].

M. Beneke, P. Falgari, S. Klein and C. Schwinn, Nucl. Phys. B **855**, 695 (2012) [arXiv:1109.1536 [hep-ph]].

A pure parton-level calculation (with stable tops) which:

- resums LP and NLP
- matched to differential NNLO ttbar
- emphasis on m_t determination from the threshold region

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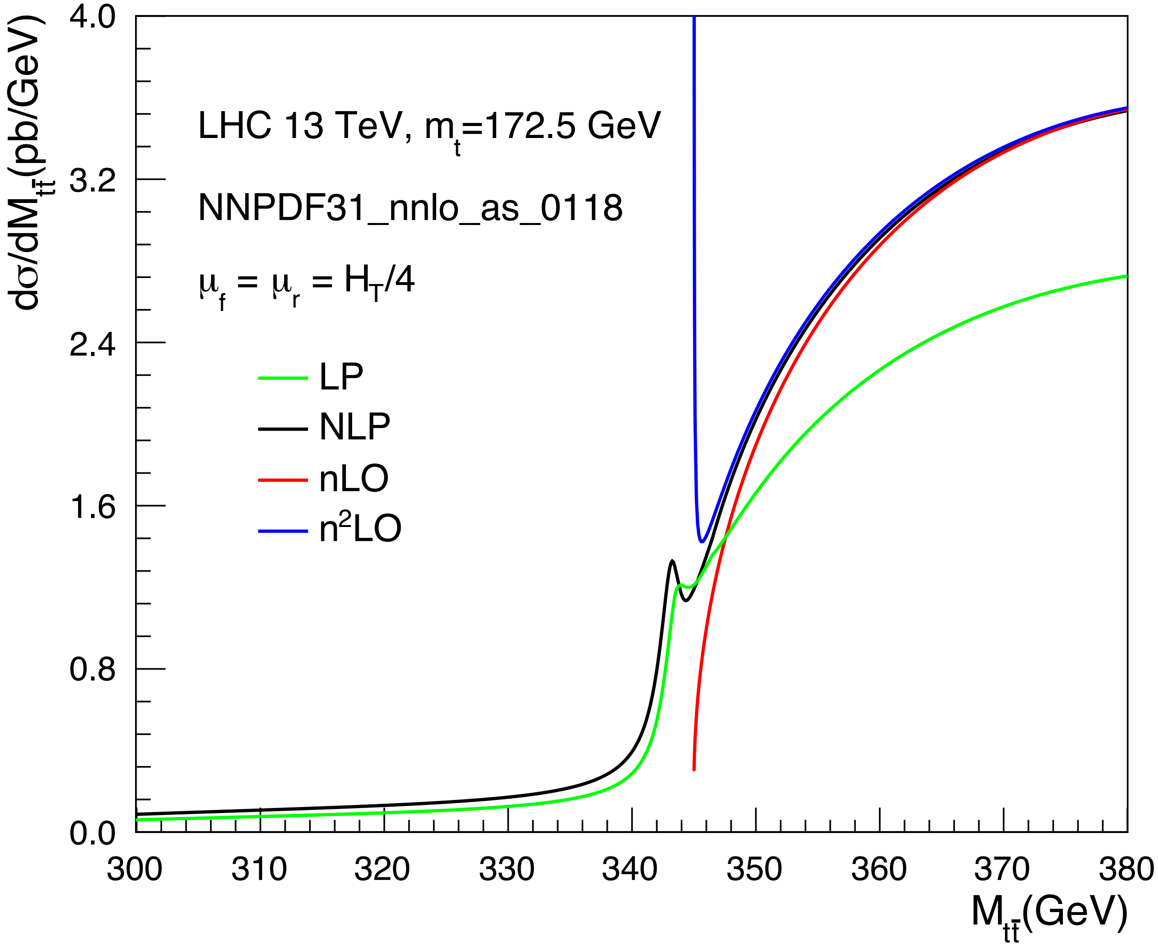
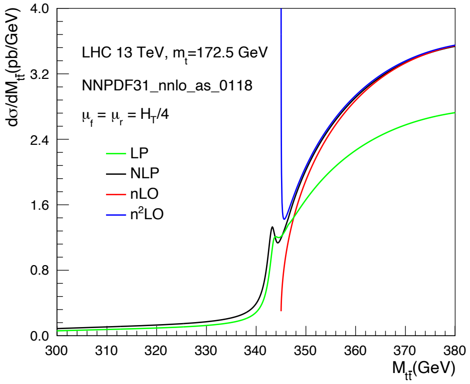


Resummation of Coulomb corrections makes the x-section well-behaved

The region below threshold has non-negligible contribution

Can these corrections be included in calculations?



Yes! (see plot to the right :)

Beyond this, they must be included at higher orders:

$$\int \frac{1}{\beta} d\Phi$$ (at NLO): finite

$$\int \frac{1}{\beta^2} d\Phi$$ (at NNLO): integrable

$$\int \frac{1}{\beta^3} d\Phi$$ (at N3LO): not integrable anymore (but in tT- the coefficient vanishes)

… (at N4LO): severe problems

Any future calculation at yet higher order must resum these effects

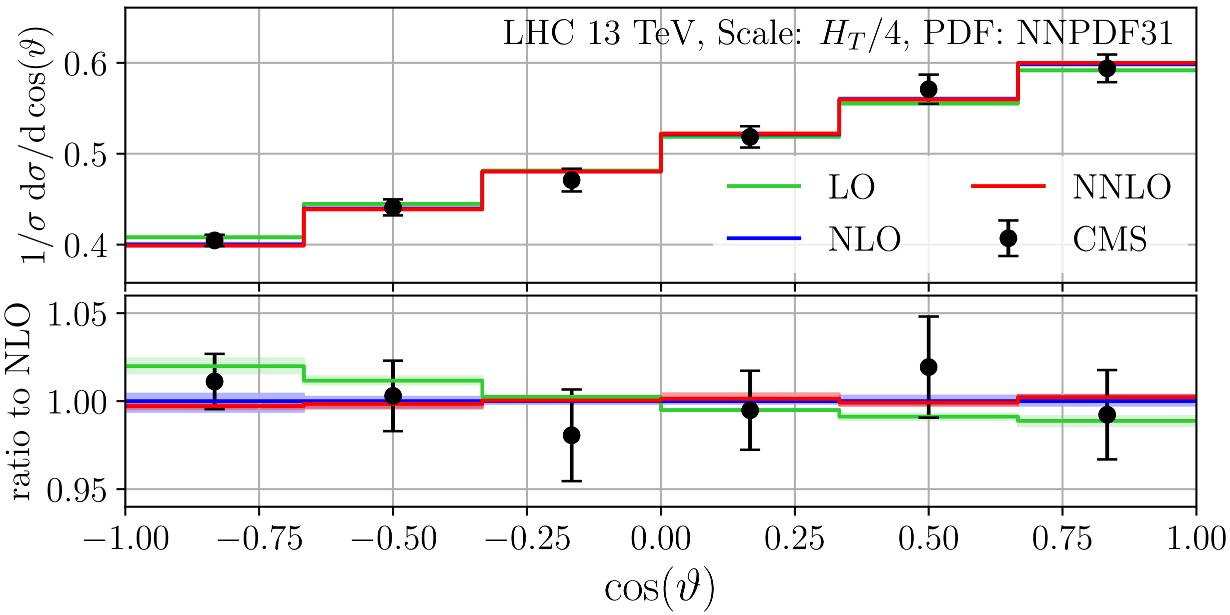
Their effect on the total x-section is small – could be larger differentially

tT spin correlations

W. Bernreuther et al arXiv:1508.05271, …
Czakon, Mitov, Poncelet arXiv:2008.11133

The calculation closest to what we are discussing today is:

- at NNLO in fixed order perturbation theory
- includes top decay through NNLO but in the narrow-width approximation (tops are produced and decayed exactly on-shell)



CMS arXiv:1907.03729

Note: fully integrated over M_{tt} above threshold